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First TSI results and status report of the CLARA/NorSat-1 solar absolute radiometer

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Abstract. The Compact Lightweight Absolute Radiometer (CLARA) is orbiting Earth on-board the Norwegian NorSat-1 micro-satellite since 14^{th} of July 2017. The first light total solar irradiance (TSI) measurement result of CLARA is 1360.18 W m^{-2} for the so far single reliable Channel B. Channel A and C measured significantly lower (higher) TSI values and were found being sensitive to satellite pointing instabilities. These channels most likely suffer from electrical interference between satellite components and CLARA, an effect that is currently under investigation. Problems with the satellite attitude control currently inhibit stable pointing of CLARA to the Sun.

Keywords. Absolute radiometer, Sun, Total Solar Irradiance

1. Introduction

The Compact Lightweight Absolute Radiometer (CLARA), built by the Physikalisch-Meteorologisches Observatorium Davos and World Radiation Center (PMOD/WRC) in Davos, Switzerland, is an electrical substitution radiometer (ESR, e.g. Brusa & Fröhlich 1986 or Schmutz *et al.* 2013) based on a new three-cavity design. It is small and lightweight, thus suitable for flying on low-cost micro satellites. CLARA is one of three payloads on the Norwegian micro satellite NorSat-1, which was launched on the 14^{th} of July 2017 from Baikonour, Kasachstan.

CLARA includes several innovations compared to the previous generation of PMO6-type (Brusa & Fröhlich 1986) radiometers built at PMOD/WRC: i) Three-cavity design for degradation tracking and redundancy; ii) Digital control-loop with feed-forward system allowing for measurement cadences of 30s; iii) Aperture arrangement to reduce internal scattered light; iv) Cavity and heat-sink design to minimize non-equivalence, size, and weight of the instrument (Walter *et al.* 2017 and Suter 2014). CLARA was end-to-end calibrated against the SI-traceable cryogenic radiometer of the TSI Radiometer Facility (TRF, Kopp *et al.* 2007) at the Laboratory for Atmospheric and Space Physics (LASP) in Boulder (Colorado). Details about the CLARA instrument design, characterization and calibration can be found in Walter *et al.* (2017).

During the four weeks of the outgassing and commissioning phase, performance tests of basic electrical signals and temperatures of CLARA were executed. The passive thermal control of the radiometer head via the front shield (Walter *et al.* 2017) was found to work very well, with temperature difference < 1K between the solar and eclipsed portions of the low-Earth-orbiting spacecraft.

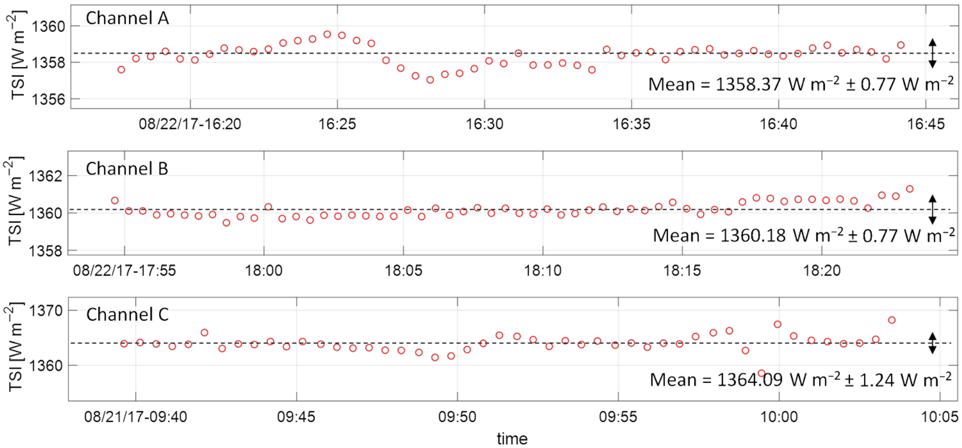

Figure 1. First light TSI measurement results of CLARA Channel A, B and C with measurement uncertainties (k=1). Channel B results are considered being the only reliable measurements so far. Channel A and C results are affected by satellite pointing instabilities (Section 3).

2. First Light TSI Results

The CLARA shutters were opened for the first TSI measurements on the 21^{st} and 22^{nd} of August 2017 (Fig. 1). Each time-series in Fig. 1 corresponds to TSI measurements during the second half of a solar portion of one orbit. Only the second half has been chosen because the satellite attitude control resulted in pointing instabilities during the first half where CLARA was not well enough pointed at the Sun to perform reliable TSI measurements. The averages of the three CLARA channels were 1358.37 W m^{-2} for Channel A, 1360.18 W m^{-2} for Channel B and 1364.09 W m^{-2} for Channel C. Channel B measured stable TSI values and was found being very little affected by the pointing instabilities or electromagnetic interference of satellite components (see Section 3) compared to Channel A and C. Therefore, CLARA Channel B TSI values are considered being reliable and correct (unlike Channel A and C) within the stated measurement uncertainty of ±0.77 W m^{-2} (k = 1, Fig. 1), which is proven by the good agreement with the VIRGO measurements. The daily average of the VIRGO radiometer was 1360.14 W m^{-2} for the 21^{st} and 1360.15 W m^{-2} for the 22^{nd}. The rather high measurement uncertainties of 0.77-1.24 W m^{-2} are mainly a result of the limitations of the end-to-end calibration at the TRF (Walter *et al.* 2017).

3. CLARA Status

3.1. *Pointing sensitivity*

The large TSI variations on the 22^{nd} of August 2017 around 16:25 from Channel A in Fig. 1 are correlated with deviations of ≈ 0.3° and ≈ 0.4° for X- and Y- angles of the satellite pointing attitude (Fig. 2). Generally, the optical design of CLARA should be insensitive to pointing variations of up to ± 1°. Detailed analysis of the basic CLARA signals preclude optical and thermal effects being responsible for the TSI measurement disturbance. That basic current and voltage signals are affected during the pointing instabilities suggests that electromagnetic disturbances affect the TSI measurements. This assumption is consistent with the fact that the two strongly affected Channels A and C are oriented towards the satellite electrical components like the magnetorquers, reaction wheels or the on-board computer, whereas Channel B is oriented towards space. Further analysis of this effect is ongoing. The satellite pointing instabilities were a result of the NorSat-1 attitude control algorithm, which was improved by the satellite manufacturer

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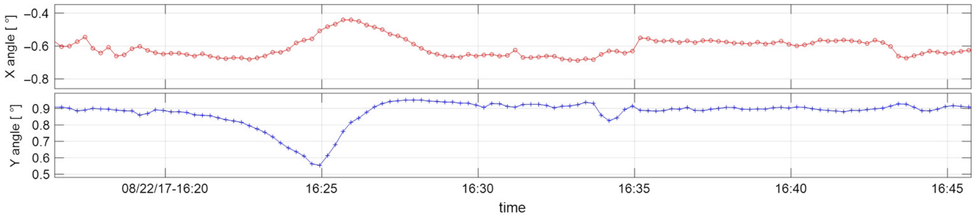

Figure 2. Pointing variations measured with the four quadrant (4Q) sensor of CLARA. A strong satellite pointing instability at 16:25 results in TSI variations of Channel A (Fig. 1).

in May 2018, significantly reducing the pointing deviations to $< 0.1°$. Merely few TSI values are available for Channel B and C for the improved pointing, showing a clear trend towards a better agreement of Channel C with Channel B measurements. The differences between Channel A and C and Channel B are thus expected being largely the result of the pointing sensitivity or the electromagnetic disturbances, respectively.

3.2. *NorSat-1 attitude control issues*

Issues with increased friction on one of the three reaction wheels providing attitude control were detected in early May 2018 by the satellite manufacturer (UTIAS-SFL). As a result, NorSat-1 tumbled several times, resulting in critically low (around -30°C) temperatures of CLARA at the end of May. The satellite manufacturer is working on improving the attitude control to be able to point CLARA back to the Sun. Because of the critically low temperatures and for safety reasons, CLARA was switched off from the end of May until mid August 2018, when CLARA was switched on for performance tests. All basic signals looked good and CLARA is ready for further TSI measurements once the attitude control issue is resolved and stable Sun pointing is obtained.

4. Conclusions

Generally, the CLARA/NorSat-1 experiment shows that flying small and lightweight TSI radiometers on low-cost micro-satellites provides new challenges. The experiment suggests that low-cost satellite components may affect TSI radiometers, at least CLARA-type radiometers. Therefore, we recommend performing more sophisticated electromagnetic susceptibility tests for CLARA-type radiometers in the future. Nevertheless, the experiment is considered successful and lessons have been learned for future missions (e.g. DARA-JTSIM/FY-3E and DARA/PROBA-3) of this new radiometer type.

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